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Spin and energy resolved near-threshold electron photoemissionfrom strained GaAs/GaAsP heterostructure

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Abstract. High resolution energy distribution curves (EDC) and a polarization versus energy distribution curves (PEDC) of the electrons, photoemitted from strained GaAs/GaAsP are presented. We have found that in the vicinity of the photothreshold the polarization does not vary across the EDC both at room and 120 K temperatures of the cathode, which shows that no depolarization occurs in the band bending region (BBR). The EDC are interpreted in terms of the competition between the electron tunneling in vacuum and hopping between the states in the band-bending region localized by the fluctuation potential.

Introduction

The photoemission from the stressed film is understood as a the three-step process, consisting of: (i) electron excitation under optical pumping, (ii) electron relaxation to the local equilibrium state and capture in the BBR, and finally, (iii) electron escape into vacuum throughout the BBR [1]. The details of the third step, i.e. electron kinetics in the BBR is still a rather controversial matter. Experimental investigations of the EDC and PEDC curves performed in unstrained GaAs cathodes showed, that, for the near bandgap excitation the electron energy distribution is spread over a broad energy band with a width close to the value of NEA [2]. It is shifted below the position of conduction-band minimum in the bulk. The polarization of the emitted electrons in this band is strongly dependent on the excitation energy, but not on the emitted electron energy. This facts may suggest that the electron energy relaxation in the BBR occurs via hopping between electronic states localized in the surface plane by the strong fluctuation potential introduced by the random spatial distribution of the ionized acceptors and donors in the BBR [3]. The localization suppresses the spin and energy relaxation processes, while the spread of the energies of the loclalized states provides broad EDC.

In this paper we report the first experimental results for the energy and polarization distribution curves of the electrons, photoemitted from a highly strained GaAs layer. We show that the observations are in line with the model of the highly localized electron states in the BBR.

1 Results

The experimental set-up was described in [2]. The sample is illuminated by σ^+ or σ^- circularly polarized light from a Ti:Sapphire or He-Ne laser normal to its surface. The photoemitted electrons are energy selected by a cylindrical 90° electrostatic deflector operating in the constant-energy mode. The full width at half maximum of the transmission function is $\Delta E \simeq 20$ meV. The polarization of the energy selected electrons is measured by a Mott detector. The sample under investigation was a 140 nm thick GaAs overlayer MOCVD

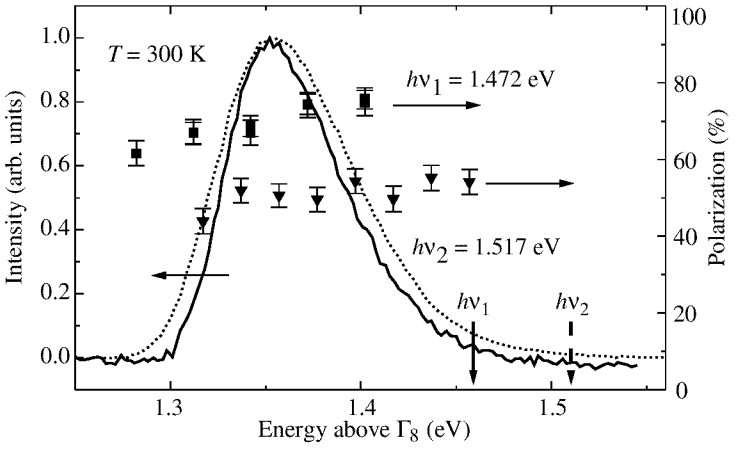

Fig. 1. Electron energy distribution and polarized electron distribution of the emitted electrons for GaAs/GaAsP strained cathode, normalized to the maximum value for two excitation energies, $T = 300$ K, energy resolution is 20 meV. Maximum position of the EDC is shown by arrow.

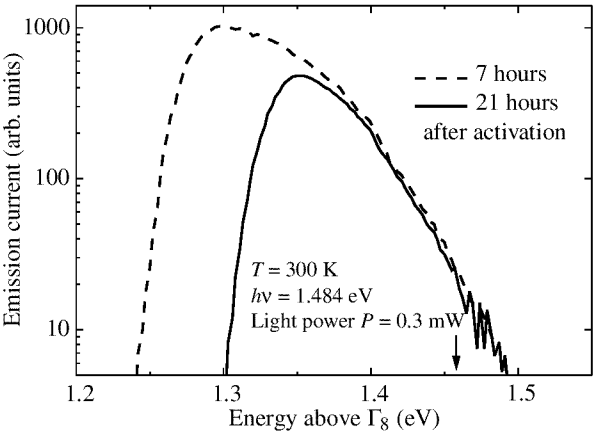

Fig. 2. Evolution of the electron energy distribution upon the degradation of the GaAs/GaAsP photocathode at $T = 300$ K, excitation energy is 1.484 eV; light power 0.01 mW. Dashed line — 7 hours, solid line — 21 hours after the activation. Band gap value is shown by arrow.

grown on a $GaAs_{0.72}P_{0.28}$ buffer at the top of commercial GaAs (001) wafer. The details of the sample structure were described in [7]. NEA state was achieved by activation of atomically clean surfaces with cesium and oxygen. The quantum yield at the poarization maximum was not less than 3×10^{-4}.

The EDC and PEDC data at room temperature are presented in Fig. 1 for two excitation energies. The position of the EDC peak is shifted down in energy as in most unstressed GaAs cathodes, though the EDC are rather narrow (FWHM does not exceed 100 meV) at room temperature. Similar curves are observed at 120 K. Besides, we have found that in the studied sample the shape of the EDC peak does not change noticeably in the excitation range in the vicinity of the photothreshold $E_g - 0.02\,\text{eV} \ll h\nu \ll E_g + 0.07\,\text{eV}$, where $E_g = 1.47$ eV. The E_g value of the film was determined by fitting of the polarization and

quantum yield spectra to the spectra calculated in the diffusion model [ ]. It is clearly seen that the polarization remains constant across EDC, so that no depolarization effects for the electrons in BBR region are registered. As a result the integrated values of the electron polarization for the $P(h\nu)$ spectrum and the P values measured at the EDC maximum (both at 20, and 80 meV resolutions) are found to be about equal at given $h\nu$.

Typical EDC spectra for the excitation energy ($h\nu = 1.484$ eV) above E_g, $h\nu - E_g \geq$ 150 mev taken in 7 and 21 hours after activation are presented in Fig. 2. The degradation of the strained-layer photocathode sample is found to be accompanied by a cut off in the low-energy part of EDC, which manifests the decrease of the effective NEA. The NEA decrease is known to be a result of the activation layer degradation due to the cesium-oxygen disbalance. In our case the degradation was accompanied by a considerable shift of the EDC low-energy threshold to the high-energy side, while the EDC high-energy edge does not change.

2 Discussion

The electronic potential in the BBR near the surface fluctuates substantially due to random distribution of ionized acceptors and Cs-originated donor centers. Therefore all the electronic states in the BBR below a certain energy defined as an electron Mobility Edge (ME) are localized also in the surface plane by the potential fluctuations. The density of the localized states $g(\epsilon)$ below the ME is a rapidly decreasing function of the localization energy ϵ in the bang gap (measured downwards from the ME). To obtain analytical results it is convenient to approximate it by an exponent, $g(\epsilon) = g_0 \exp(-\epsilon/\gamma)$, where g_0 is the density of states at the ME energy. The estimated and measured time of the electron emission from the BBR in vacuum $\tau_{\text{emi}} \approx 10$ ps is much larger that the time of the delocalized electron energy relaxation due to the emission of the phonons, whereas below ME the electron energy relaxation is suppressed since the number of the final localized states in the nearest vicinity of a given localized state is diminishing with energy. The emitted electron energy distribution is formed as a result of competition of the processes of the electron emission in vacuum and the electron hopping down in energy in the tail states. We will assume the probability for the electron to emit a phonon $\tau_{\text{hop}}^{-1}(\epsilon)$ to be proportional below ME to the average density of the final electron states. Similar model was developed for interpretation of the luminescence spectra in mixed crystals in Ref. [ ].

In the case when the emitted phonon energy is smaller than the EDC pear width, the calculated electron emission current energy dependence $J_{\text{emi}}(\epsilon)$ is

$$J_{\text{emi}}(\epsilon) = J_{\text{emi}}(0) \exp\left[\frac{\epsilon}{\gamma} - \alpha\left(\exp\left(\frac{\epsilon}{\gamma}\right) - 1\right)\right], \tag{1}$$

where the parameter α is given by $\alpha = 2\tau_{\text{hop}}(0)\gamma/(\tau_{\text{emi}}\delta^2 g_0 a_0^2)$, τ_{emi} is the time of the electron emission from the BBR in vacuum, δ is the average emitted phonon energy, and a_0 is the average localization radius of the tail states at the emission peak energy. The results of the calculation of the EDC together with the experimental curve are shown in Fig. 3. It is seen that the shape of the experimental EDC is susessfuly reproduced. The fitting of the Eq. (1) dependence to experimental data gives $\gamma = 30$ meV, $\alpha = 0.08$, in line with theoretical estimations.

The depolarization decline below the conduction band energy is the consequence of the localization of the electron states in this energy region, since the main D'yakonov-Perel' spin-relaxation mechanism is not effective for the localized states. The changes of the EDC with temperature are found to be mainly due to the thermal variation of the band gap.

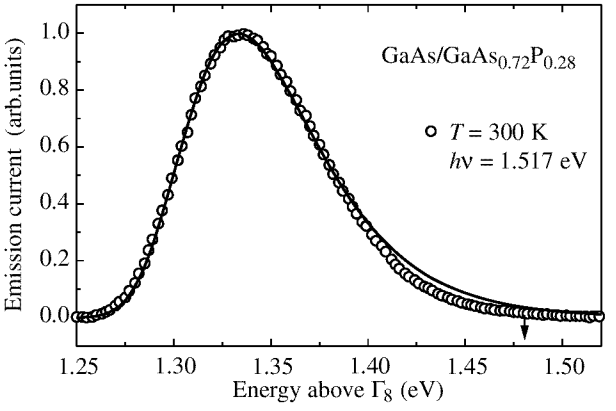

Fig. 3. Experimental electron energy distribution curve $T = 300$ K, together with results of the calculation (solid line) using the localized states model. Band gap value is shown by arrow.

In conclusion, the EDC and PEDC measurements for the strained GaAs layer surface activated to NEA, demonstrate the electron capture to the band bending region before emission. The shape of the energy distribution peak is in good agreement with the results of the model of the emission from the states localized in the surface plane by the fluctuations of the surface potential. The localization is also manifested by switching off the spin relaxation across the emission peak.

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